

We claim:

1. A method for generating GPS satellite clock corrections, comprising:
 - obtaining dual-frequency pseudorange code measurements and carrier-phase measurements from a plurality of satellites;
 - for each of the plurality of satellites, forming a smoothed refraction-corrected code measurement based on the dual-frequency pseudorange code measurements and carrier-phase measurements from the satellite; and
 - computing clock corrections for the plurality of satellites based on the smoothed refraction-corrected code measurements.
2. The method of claim 1 wherein forming the smoothed refraction-corrected code measurement for each satellite comprises:
 - for each of a series of measurement epochs preceding and including a current measurement epoch, forming a refraction-corrected code measurement based on the dual frequency pseudorange code measurements from the satellite and a refraction-corrected carrier-phase measurement based on the dual-frequency carrier phase measurements from the satellite; and
 - smoothing the refraction-corrected code measurements with the refraction-corrected carrier phase measurements to obtain a smoothed refraction-corrected code measurement at the current measurement epoch.
3. The method of claim 2 wherein smoothing the refraction-corrected code measurement comprises:
 - computing a smoothed offset between the refraction corrected code measurements and the refraction corrected carrier-phase measurements; and
 - forming the smoothed refraction corrected code measurement by adding the refraction corrected carrier-phase measurement at the current measurement epoch to the smoothed offset.
4. The method of claim 2 wherein smoothing the refraction-corrected code measurement comprises:
 - forming projections of the smoothed refraction-corrected code measurements using changes in the carrier-phase measurements between two consecutive measurement epochs;

computing an expanding average of differences between the projections and the refraction-corrected code measurements over a series of measurement epochs.

5. The method of claim 1 wherein the dual-frequency pseudorange code measurements and carrier-phase measurements from each of the plurality of satellites include a pseudorange code measurement and a carrier-phase measurement corresponding to each of two carrier signal frequencies and at each of a series of measurement epochs, and wherein forming the smoothed refraction-corrected code measurement for each satellite comprises:

for each of the series of measurement epochs and for each carrier signal frequency, forming a linear combination of the carrier-phase measurements corresponding to the two carrier signal frequencies from the satellite, such that the linear combination of the carrier-phase measurements matches ionospheric refraction effects on the pseudorange code measurement for the carrier signal frequency from the satellite;

forming a smoothed code measurement for each carrier signal frequency by smoothing the pseudorange code measurements for the carrier signal frequency with the matching linear combinations of the dual-frequency carrier-phase measurements; and

computing the smoothed refraction-corrected code measurement based on the smoothed code measurements for the two carrier signal frequencies.

6. The method of claim 1 wherein the dual-frequency pseudorange code measurements and carrier-phase measurements are obtained at a reference GPS receiver having a known location and wherein computing the clock corrections comprises:

computing a residual for each of the plurality of satellites by subtracting a theoretical range between the reference GPS receiver and the satellite from the smoothed refraction-corrected code measurement for the satellite;

forming a mean receiver clock error as a linear combination of the residuals for the plurality of satellites; and

computing a clock correction for each of the plurality of satellites by subtracting the mean receiver clock error from the residual computed for the satellite.

7. The method of claim 6 wherein the theoretical range includes an adjustment for tropospheric effects.
8. The method of claim 6 wherein the theoretical range includes an adjustment for satellite orbital errors.
9. The method of claim 6 wherein the residuals in the linear combination are weighted according to elevation angles of the plurality of satellites as observed by the reference GPS receiver.
10. A method for generating satellite clock correction for a first satellite among a plurality of satellites in a wide-area GPS network having a plurality of reference stations including a master reference station and a plurality of local reference stations, comprising:
 - obtaining smoothed refraction-corrected code measurements corresponding to GPS measurements taken at some or all of the plurality of reference stations;
 - for each of a group of satellites visible at the master reference station, computing a clock correction associated with the master reference station using the smoothed refraction-corrected code measurements corresponding to GPS measurements taken at the master reference station;
 - for each of a group of local reference stations at which the first satellite is visible, computing a clock correction associated with the local reference station for the first satellite using the smoothed refraction-corrected code measurements corresponding to GPS measurements taken at the local reference station and the clock corrections associated with the master reference station for satellites visible at both the master reference station and the local reference station; and
 - forming a linear combination of the clock corrections for the first satellite, the clock corrections in the linear combination being associated with different reference stations at which the first satellite is visible.
11. The method of claim 10, further comprising:
 - adding a local reference station at which the first satellite is visible to the group of local reference stations to form a new group of local reference stations;
 - for each of the new group of local reference stations, computing a clock correction associated with the local reference station for the first satellite using the

smoothed refraction-corrected code measurements corresponding to the GPS measurements taken at the local reference station and the linear combination; and
forming a new linear combination of the clock corrections for the first satellite, the new linear combination being associated with different reference stations at which the first satellite is visible.

12. The method of claim 10 wherein the clock corrections in the linear combination are weighted according elevation angles at which the satellite is visible to the different reference stations.

13. The method of claim 10 wherein obtaining smoothed refraction corrected code measurements corresponding to GPS measurements taken at some or all of the plurality of reference stations comprises:

for each reference station among the some or all of the plurality of reference stations and for each satellite visible at the reference station,

forming refraction-corrected code measurements and refraction-corrected carrier-phase measurements using dual-frequency GPS pseudorange measurements and carrier-phase measurements, respectively, based on signals received from the satellite at the reference station at a series of measurement epochs; and

smoothing the refraction corrected code measurements with the refraction corrected carrier-phase measurements to form a smoothed refraction corrected code measurement.

14. The method of claim 10 wherein obtaining smoothed refraction corrected code measurements corresponding to GPS measurements taken at some or all of the plurality of reference stations comprises:

for each reference station among the some or all of the plurality of reference stations and for each satellite visible at the reference station,

forming at each of a series of measurement epochs and for each carrier signal frequency a linear combination of dual frequency carrier-phase measurements such that the linear combination matches the ionospheric refraction effect on a corresponding pseudorange code measurement;

computing a smoothed code measurement for each carrier signal frequency by smoothing the pseudorange code measurements for the carrier

signal frequency with the corresponding linear combinations of the dual frequency carrier-phase measurements; and

combining the smoothed code measurements to form a smoothed refraction-corrected code measurement.

15. The method of claim 10 wherein computing the clock correction associated with the master reference station for a satellite visible at the master reference station comprises:

obtaining a master residual for each satellite visible at the master reference station, the master residual representing a difference between a smoothed refraction-corrected code measurement corresponding to GPS measurements taken at the master reference station and a theoretical range between the satellite and the master reference station;

computing a master mean receiver clock error based on the master residuals; and

subtracting the master mean receiver clock error from the master residuals.

16. The method of claim 15 wherein computing the master mean receiver clock error comprises forming an average of the master residuals over the satellites visible at the reference station.

17. The method of claim 15 wherein computing the master mean receiver clock error comprises forming a linear combination of the master residuals weighted by elevation angles of the satellites as observed by the master reference station.

18. The method of claim 15 wherein computing the clock correction associated with the local reference station comprises:

obtaining a local residual for each satellite visible at both the master reference station and the local reference station, the local residual representing a difference between a smoothed refraction-corrected code measurement corresponding to GPS measurements taken at the local reference station and a theoretical range between the satellite and the local reference station;

computing a local mean receiver clock error based on the local residuals and the master residuals; and

subtracting the local mean receiver clock error from the local residuals.

19. The method of claim 18 wherein the theoretical range between a reference station and a satellite visible to the reference station includes an adjustment for the tropospheric refraction effects on the GPS measurements obtained at the reference station for the satellite.

20. The method of claim 18 wherein the theoretical range between a reference station and a satellite visible to the reference station includes an adjustment for the satellite orbital errors in the GPS measurements obtained at the reference station for the satellite.

21. The method of claim 18 wherein computing the local mean receiver clock error comprises:

for each satellite common to the local reference station and the master reference station, computing an offset of the local residual from the master residual; and

forming a linear combination of the offsets over the satellites common to the local reference station and the master reference station.

22. The method of claim 21 wherein the offsets in the linear combination are weighted by elevation angles of the satellites as observed by the local reference station.

23. A method for forming a smoothed refraction-corrected code measurement based on dual-frequency GPS pseudorange measurements and carrier-phase measurements taken from a satellite by a GPS receiver, comprising:

for each of a series of measurement epochs preceding and including a current measurement epoch, forming a refraction-corrected code measurement based on the dual frequency pseudorange code measurements from the satellite and a refraction-corrected carrier-phase measurement based on the dual-frequency carrier phase measurements from the satellite; and

smoothing the refraction-corrected code measurements with the refraction-corrected carrier phase measurements to obtain a smoothed refraction-corrected code measurement at the current measurement epoch.

24. The method of claim 23 wherein smoothing the refraction-corrected code measurement comprises:

computing a smoothed offset between the refraction corrected code measurements and the refraction corrected carrier-phase measurements; and

forming the smoothed refraction corrected code measurement by adding the refraction corrected carrier-phase measurement for the current measurement epoch to the smoothed offset.

25. The method of claim 23 wherein smoothing the refraction-corrected code measurement comprises:

forming projections of the smoothed refraction-corrected code measurements using changes in the carrier-phase measurements between two consecutive measurement epochs;

computing an expanding average of differences between the projections and the refraction-corrected code measurements over a series of measurement epochs.

26. A method for forming a smoothed refraction-corrected code measurement based on dual-frequency GPS pseudorange measurements and carrier-phase measurements taken from a satellite at a GPS receiver, comprising:

forming at each of a series of measurement epochs and for each carrier signal frequency a linear combination of the dual-frequency carrier-phase measurements to match the ionospheric refraction effect on the corresponding pseudorange code measurement;

forming a smoothed code measurement for each carrier signal frequency by smoothing the pseudorange code measurements with the matching linear combinations of the dual-frequency carrier-phase measurements; and

combining the smoothed code measurements to form the smoothed refraction-corrected code measurement.

27. A computer readable medium comprising computer executable program instructions that when executed cause a digital processing system to perform a method for generation GPS satellite clock corrections, the method comprising:

obtaining dual-frequency pseudorange code measurements and carrier-phase measurements from a plurality of satellites;

for each of the plurality of satellites, forming a smoothed refraction-corrected code measurement based on the dual-frequency pseudorange code measurements and carrier-phase measurements from the satellite; and

computing clock corrections for the plurality of satellites based on the smoothed refraction-corrected code measurements.

28. A computer readable medium comprising computer executable program instructions that when executed cause a digital processing system to perform a method for generation satellite clock corrections a first satellite among a plurality of satellites in a wide-area GPS network having a plurality of reference stations including a master reference station and a plurality of local reference stations, the method comprising:

- obtaining smoothed refraction-corrected code measurements corresponding to GPS measurements taken at some or all of the plurality of reference stations;

- for each of a group of satellites visible at the master reference station, computing a clock correction associated with the master reference station using the smoothed refraction-corrected code measurements corresponding to GPS measurements taken at the master reference station;

- for each of a group of local reference stations at which the first satellite is visible, computing a clock correction associated with the local reference station for the first satellite using the smoothed refraction-corrected code measurements corresponding to GPS measurements taken at the local reference station and the clock corrections associated with the master reference station for satellites visible at both the master reference station and the local reference station; and

- forming a linear combination of the clock corrections for the first satellite, the clock corrections in the linear combination being associated with different reference stations at which the first satellite is visible.